Forensic Science International: Synergy 2 (2020) 164–172

Contents lists available at ScienceDirect

Forensic Science International: Synergy

journal homepage: https://www.journals.elsevier.com/forensic-science-international-synergy/

Data driven optimization of sexual assault case processing

M. Bazinet[*, 1], J. Larose [1], S. Noël, J. Comte, M. Primeau, M. Lapointe, C. Paquet, R. Landry, L. Croteau, F. Gingras

Laboratoire de sciences judiciaires et de médecine légale, 1701 Parthenais, Montréal, Québec, H2K 3S7, Canada

ARTICLE INFO

Article history:
Received 14 May 2020
Received in revised form
27 May 2020
Accepted 27 May 2020
Available online 30 May 2020

Keywords:
Sexual assault evidence kit (SAEK)
Time since intercourse (TSI)
Skin swab
Washing
DNA profile

ABSTRACT

In recent years, several forensic laboratories have noted an increase in the number of sexual assault cases submitted for testing, often leading to longer turnaround times. In that context, forensic laboratories may be interested in reviewing their procedures to increase productivity. Here, we present two different strategies that were put in place in our laboratory. First, we changed the way sexual assault evidence kits (SAEK) are processed by implementing an optimized workflow that prioritizes the internal samples (vaginal, anal, and oral). This new procedure allowed for a drastic decrease in turnaround time, while maintaining a similar investigative power.

Secondly, we used data from casework to target cases and samples that were likely to yield biological material from the perpetrator, in an attempt to avoid dedicating time and effort to cases for which there is a very low probability of obtaining foreign DNA evidence. Among other things, we looked at the likelihood of obtaining DNA from the perpetrator when the complainant reported the use of a condom, has showered after the assault or when the complainant has no memory of the assault. Results show that those circumstances do not dramatically decrease the probability of finding DNA from the perpetrator.

1. Introduction

DNA is one of the main pieces of evidence in sexual assault investigations. In most jurisdictions, a sexual assault evidence kit (SAEK, also called rape kit) is used to ensure the standardized collection of forensic samples and preserve the integrity of the chain of custody for legal proceedings. Over the last few years, the mediatisation of court cases and social movements such as #MeToo has led to an increase in the number of police-reported sexual assaults [1]. Even though not all victims of sexual assault complete evidence kits [2–5], this augmentation of reported sexual assault cases could lead to a swell of SAEKs sent to forensic laboratories. Moreover, in recent years, large stores of untested kits have been discovered in several jurisdictions in the United States [6–8] and many initiatives and strategies were put in place to prioritize and process the untested kits [9–13].

In this context, many laboratories are looking at ways to improve their efficiency in processing rape kits. In the province of Quebec (Canada), the SAEK contains standardized body samples collection material (vaginal, anal, oral, skin) as well as containers and procedures to collect additional evidentiary items such as clothing, bedding, condoms, feminine hygiene products and other relevant items. Although periodical modifications were made to the kit over the years, the processing of samples in the forensic laboratory has not significantly changed during the past 20 years. However, as more and more sexual assault cases were received, it became necessary to review our procedures to increase productivity. The goal was to reduce turnaround time while maintaining the same investigative power, defined as the proportion of cases for which a foreign DNA profile is obtained. Two complementary strategies were put in place and are presented in this paper. First, we changed the way SAEKs are processed by implementing an optimized workflow through which the most relevant samples are prioritized and automatically processed. Secondly, we used data from casework for decision-making to allocate resources to cases and exhibits where the probability of obtaining probative DNA evidence was substantial. The following questions were addressed:

- What is the maximal time since intercourse for which a foreign DNA profile was obtained? Are time-since-intercourse recommendations appropriate for all sample type?

* Corresponding author.
E-mail address: martine.bazinet@msp.gouv.qc.ca (M. Bazinet).
[1] Bazinet M and Larose J these two authors contributed equally to this work.

https://doi.org/10.1016/j.fsisyn.2020.05.003

- Does having two different vaginal samples provide complementary or redundant information?
- Is it possible to obtain a foreign DNA profile from vaginal or anal samples when the complainant reported the use of a condom?
- What is the probability of obtaining a foreign DNA profile when the complainant has no memory of the event?
- Is it possible to obtain a foreign DNA profile from skin swabs when the complainant mentions bathing or showering after the assault?
- When supplementary items such as skin swabs, clothing or bedding are sent, is it worth examining them?

2. Material and method

2.1. Sexual assault cases processing

2.1.1. Extensive workflow

Before 2015, the processing of sexual assault cases in the province of Quebec (Canada), was carried out in an extensive way, as shown in Fig. 1A. The first step was the reception of the sexual assault evidence kit (and supplementary evidence in some cases) at the forensic laboratory. The case was then assigned to a DNA analyst; depending on the resources available, it could take weeks or even months for the case to be assigned. Then, the DNA analyst typically screened all body samples and additional evidentiary items for body fluids and sent them for differential DNA extraction (DNA IQ™, Promega) and amplification (Identifiler®Plus, Thermo Fisher). When all the results were available, the DNA analyst assessed the case and wrote the report. Communication with the case investigator took place only when needed, for example when the reference profile of a consensual partner was required.

2.1.2. Optimized workflow

An optimized workflow for the processing of sexual assault cases was implemented in 2015 (Fig. 1B). It brought about three major changes: 1) samples were prioritized and automatically processed 2) some tasks that were previously carried out by DNA analysts were transferred to laboratory technicians 3) communication with law enforcement agencies was improved.

The optimized workflow includes two separate stages. As soon as the kit is received at the forensic laboratory, Stage I starts automatically and internal samples (vaginal swab, vaginal rinse, anal swab, mouth rinse) are processed by technicians. These samples were chosen as the first exhibits to be analyzed due to their intimate nature and direct link to sexual offences. Once available, the Stage I results and the casefile are then reviewed by a DNA analyst who informally discloses them to the case investigator by phone or email so that both parties can evaluate/discuss whether the acquired information is sufficient or if the analysis of additional exhibits is required. When no further analysis is required, the remaining samples and exhibits are not examined and the report is

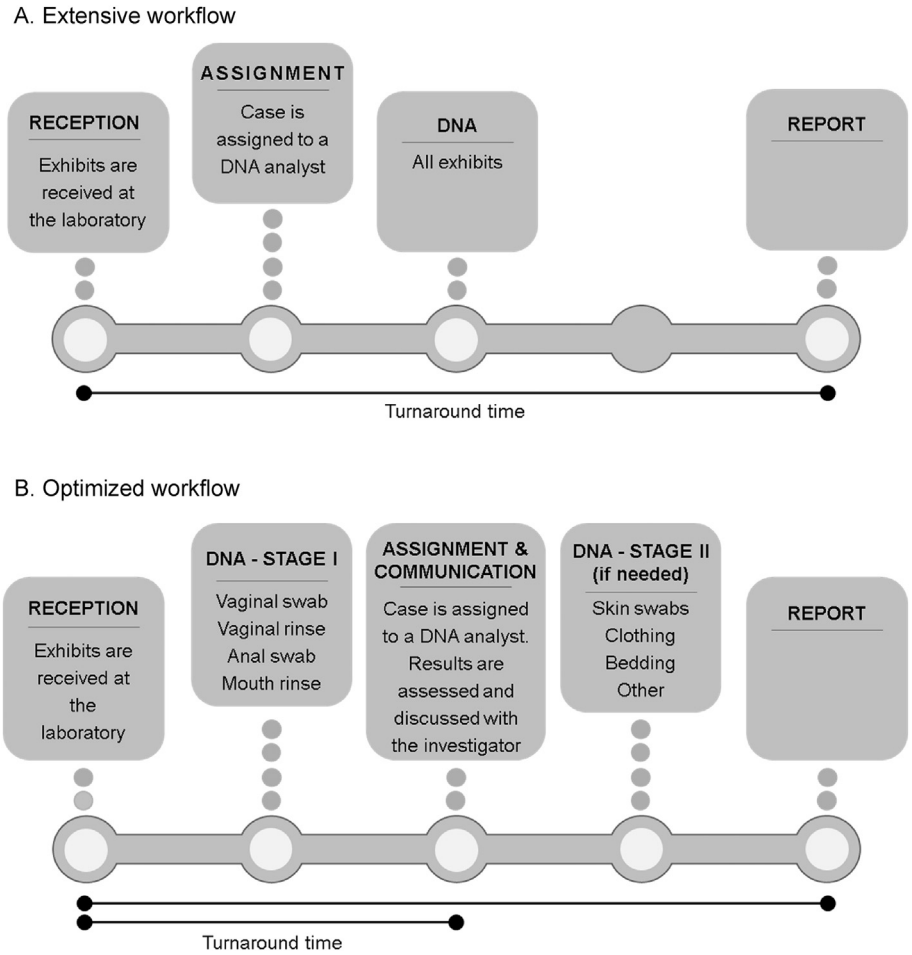

Fig. 1. Workflows used to process sexual assault cases. A) Extensive workflow in place before 2015. B) Optimized workflow implemented to increase productivity. When Stage II samples are not needed, the report can usually be written immediately after the communication with the investigator, effectively reducing turnaround-time.

written as is. On the other hand, when further analysis is deemed necessary, Stage II is launched for the case and additional samples such as skin swabs, undergarments, clothing and other exhibits are processed.

2.1.3. Evaluation of the performance of the optimized workflow

To evaluate the efficiency of the optimized workflow, a comparative study was performed using 1128 cases, half having been processed with the extensive workflow and half with the optimized workflow. For all cases, the three following criteria were respected: 1) there is only one complainant and one SAEK; 2) the complainant is at least 12 years old; 3) the complainant did not report having consensual intercourse within 5 days prior to the forensic medical examination.

The turnaround time, defined as the number of days between the reception of the SAEK at the forensic laboratory and the communication of results (whether partial or complete) to the investigator, was assessed. The proportion of cases for which the turnaround time was less than 30, 60, 90 or 120 days was calculated, as well as the median turnaround time. The investigative power, defined as the proportion of cases for which a foreign DNA profile was obtained, was also evaluated for both workflows. Finally, the reduction of resources dedicated to the processing of sexual assault cases with the optimized workflow was assessed by looking at cases for which no supplementary analyses were requested after the communication of the Stage I results.

2.2. Resource allocation

Because human and financial resources are limited in a forensic laboratory, we wanted to allocate resources to cases and samples that were likely to yield biological material from the perpetrator, and conversely avoid wasting time and effort on those for which there was a very low probability of obtaining probative DNA evidence. We also wanted to eliminate unnecessary redundancy of results within a case. To do so, we collected data from the 564 cases processed with the optimized workflow to look at the questions presented in the following sections.

2.2.1. Are the time since intercourse recommendations appropriate for all sample types?

The probability of recovering biological material from the perpetrator on or inside the body of the complainant is dependent, among other things, on time since intercourse (TSI). In our jurisdiction, samples are typically not collected if they exceed their maximal TSI [14]. Yet, we decided to assess if the maximal TSIs established previously were still appropriate despite the increased sensitivity of commercial STR kits or if they should be extended to increase the investigative power, as we changed from Profiler Plus®/COfiler® to Identifiler® Plus (ThermoFisher) in 2010. The proportion of samples for which a foreign DNA profile was obtained for different TSIs was recorded for all samples included in the SAEK: vaginal (swab and rinse), skin swab, anal swab and mouth rinse.

2.2.2. Does having two different vaginal samples provide complementary or redundant information?

Two vaginal samples are included in the SAEK: a vaginal swab and a vaginal rinse, which is thought to recover biological material potentially present deeper in the vaginal cavity. Cases for which both samples (swab and rinse) were analyzed were used to evaluate if there is a real benefit of having two vaginal samples or if the information provided is redundant.

2.2.3. Is it possible to obtain a foreign DNA profile from vaginal or anal samples when the complainant reported the use of a condom?

It might be thought that if the assailant used a condom, there is a very low probability of obtaining valuable DNA evidence from vaginal or anal samples. To test this hypothesis, we used cases for which the use of a condom was reported and we examined the proportion of vaginal and anal samples for which a foreign DNA profile was obtained.

2.2.4. What is the probability of obtaining a foreign DNA profile when the complainant has no memory of the event?

For different reasons (intoxication, disability, trauma or disease) the complainant may not recall the details of the sexual assault and may not even be sure that an assault did occur. In such cases where information is missing to guide the collection of forensic evidence, is DNA analysis still relevant? To assess this question, we compared the proportion of cases for which a foreign DNA profile was obtained when the complainant did or did not recall the details of the event.

2.2.5. Is it possible to obtain foreign DNA profiles from skin swabs when the complainant mentions bathing or showering after the assault?

When the complainant reports washing themself after the assault it could be thought that DNA evidence deposited on skin would have been washed away. The relevance of processing skin swabs in those cases can thus be challenged. The proportion of skin swabs for which a foreign DNA profile was obtained when the complainant reported washing was therefore compared to when the complainant did not wash.

2.2.6. Is it worth examining and analyzing supplementary items such as skin swabs, clothing and bedding?

Skin swabs, undergarments, clothing, bedding and various items are sometimes also submitted for analysis. Because of their heterogeneity, the processing of these items cannot be standardized and each exhibit has to be examined and sampled according to its nature and the circumstances of the case. Considering the additional resources needed for the examination and sampling of supplementary evidence, we looked into the proportion of these types of exhibits for which a foreign DNA profile was obtained.

For clothing and bedding that were processed, only those for which no profile were obtained from the internal samples were considered. Although a small number of undergarments, clothing and bedding belonging to the suspect were received, only items belonging to the complainant were considered for simplification of data collection.

2.3. Classification of DNA evidence (foreign and relevant profiles)

All DNA profiles that could not be attributed to the complainant were scrutinized. Of those, good-quality profiles suitable for comparison were considered as foreign profiles. Owing to social interactions and the persistence of DNA on clothing, skin swabs and samples from supplementary evidence could harbor DNA unrelated to the sexual assault. Therefore, results from those types of samples were further classified as relevant DNA evidence when there was a high probability that they belonged to the assailant. A result was labelled as relevant only when the profile corresponded to a profile found on an internal sample or to the suspect's profile. When none of these conditions were met, the profile was simply labelled as foreign. By using this classification, relevant profiles are a subset of foreign profiles and while relevant profiles are necessarily foreign, foreign profiles may not be relevant.

3. Results

3.1. Performance of the optimized workflow

Following the implementation of the optimized workflow, we assessed its performance using turnaround time, investigative power and reduction of exhibits examined.

3.1.1. Turnaround time

The number of days between the reception of the SAEK at the laboratory and the communication of results to the investigator was compared for 1128 casefiles processed with the extensive or the optimized workflow. When processing SAEKs with the extensive workflow, the median turnaround time was 140 days; this number decreased to 45 days for the optimized workflow. Furthermore, the proportion of cases for which results were communicated to the investigator within 30, 60, 90 or 120 days was higher with the optimized workflow (Fig. 2).

3.1.2. Investigative power

To make sure that the implementation of the optimized workflow did not compromise the capacity of the laboratory to provide investigative evidence, we compared the proportion of cases for which a foreign DNA profile was obtained for both workflows. A foreign DNA profile was obtained for 53% of the cases processed with the extensive workflow, compared to 44% for the optimized workflow (Fig. 3). Further analysis showed that for the optimized workflow, 60% of the foreign DNA profiles were provided by at least one Stage I sample and the remaining 40% was provided by Stage II samples.

3.1.3. Reduction of exhibits examined

When cases are processed with the optimized workflow, internal samples are prioritized while skin swabs and supplementary evidence are processed in a second stage, only when needed. Among the 564 cases processed following the optimized workflow, 414 cases contained a total of 1550 Stage II samples (skin swabs, clothing, bedding or other items). For almost half of the cases (n = 197, 48%), results from Stage I (internal samples) were considered satisfactory and the analysis of Stage II items was not required. This prevented the unnecessary analysis of about 43% of stage II samples (n = 670/1550).

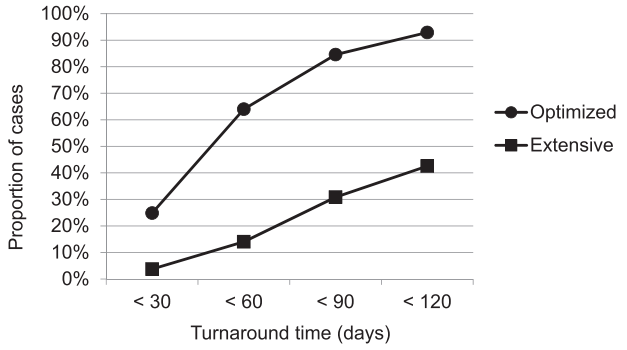

Fig. 2. Turnaround time, calculated as the number of days between the reception of the SAEK at the forensic laboratory and the communication of results to the investigator, for casefiles processed with the extensive (n = 564) and the optimized (n = 564) workflows.

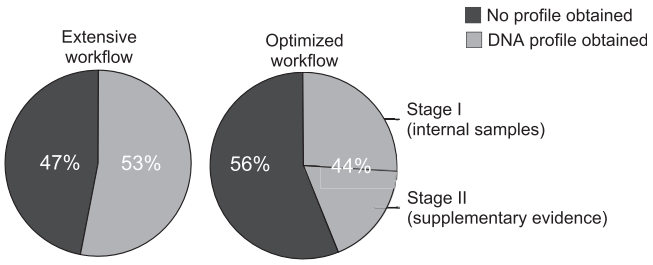

Fig. 3. Proportion of cases for which a foreign DNA profile was obtained for the extensive and the optimized workflows.

3.2. Resource allocation

To increase productivity, we wanted to allocate resources to cases and samples for which there was a reasonable probability of obtaining probative DNA evidence. Different scenarios were examined.

3.2.1. Time since intercourse (TSI)

To assess if the maximal TSIs established in 2009 were still appropriate despite the increased sensitivity of commercial STR kits, we calculated the proportion of samples for which a foreign DNA profile was obtained for different TSIs for all samples included in the SAEK: vaginal (swab and rinse), anal swab, mouth rinse and skin swab (Fig. 4). For all sample types, as TSI increased, a decreasing proportions of samples provided a foreign DNA profile. A maximum of 5% of vaginal, anal and buccal samples provided a foreign DNA profile in the longest recommended TSI. For skin swab, this proportion was slightly larger (14%), but the maximum TSI for which a foreign DNA profile was obtained was 35 h, well below the maximum recommended TSI of 48 h (Table 1).

3.2.2. Vaginal swab versus vaginal rinse

To assess if there is a real advantage of collecting two vaginal samples (a swab and a rinse), 143 cases for which a foreign DNA profile was obtained for at least one vaginal sample were examined. In most cases, the same profile was obtained from both samples (Fig. 5). Yet, for all TSI intervals, there were cases for which a profile was established from only one of the two vaginal samples. However, there was no clear indication that one type of sample consistently performs better than the other and data for the longest TSI should be interpreted with caution because of small sample sizes. Overall, the same result was obtained from both samples in 84% of cases, only from the swab in 9.7% of cases and only from the rinse in 6.3% of cases.

3.2.3. Use of a condom reported

We examined 34 cases, all committed against female complainants, to assess whether the use of a condom during the assault prevented the detection of biological material from the perpetrator. A foreign DNA profile was obtained from at least one vaginal sample for 27% of the cases for which vaginal penetration with a condom was reported (n = 33). There was only one case in which the complainant reported an anal penetration with condom; a foreign DNA profile was established from the anal swab in that case.

3.2.4. Memory loss

To assess if DNA analysis is still effective even though complainants do not remember the details of the sexual assault, we compared the proportion of samples in which a foreign DNA profile was obtained when the complainant did or did not remember the details of the assault. The complainant reported memory loss in 285 out of 564 cases and a foreign DNA profile was obtained in 40% of

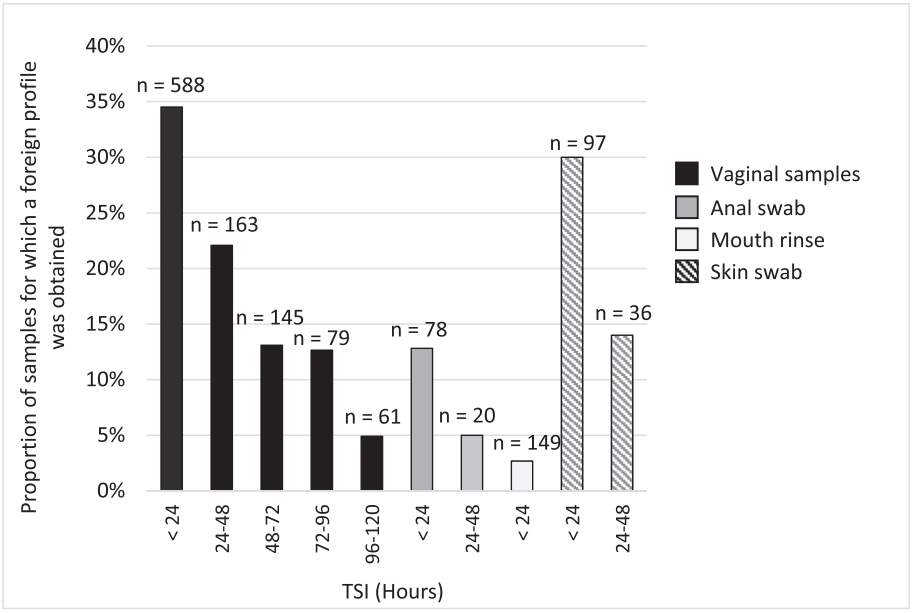

Fig. 4. Proportion of samples for which a foreign DNA profile was obtained according to time since intercourse (TSI) for vaginal, anal, oral and skin samples.

Table 1
Comparison of the maximum time since intercourse (TSI) recommended and the maximum TSI for which a foreign DNA profile was obtained for all sample types.

Sample type	Maximum TSIrecommended	Maximum TSI for which aforeign DNA profile was obtained
Vaginal swab	120 h	115 h
Vaginal rinse	120 h	101 h
Skin swab	48 h	35 h
Anal swab	48 h	34 h
Mouth rinse	24 h	9 h

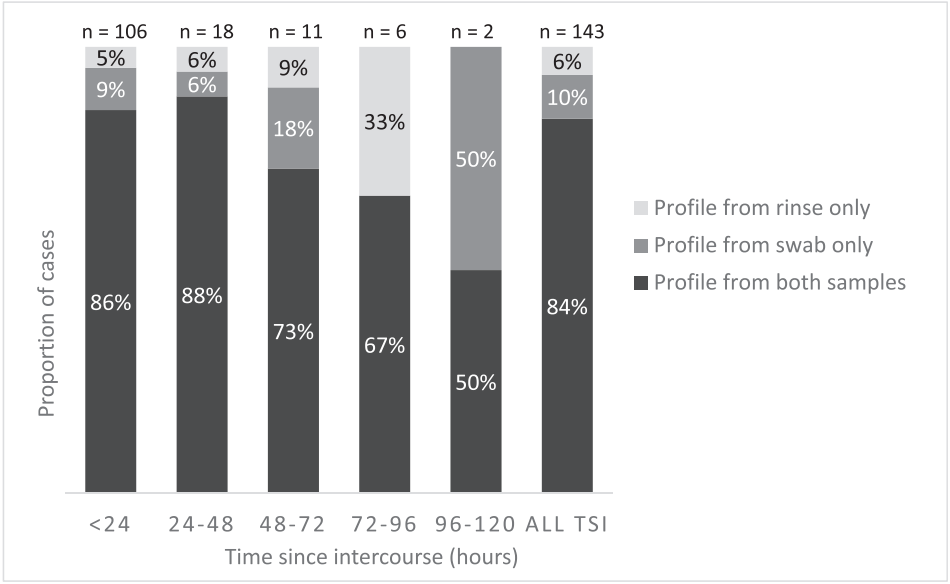

Fig. 5. Proportion of cases for which a foreign DNA profile was obtained from both vaginal samples, only from the vaginal swab or only from the vaginal rinse. Data were compiled by TSI ranges and globally.

these cases. Comparatively, when the complainant did not report memory loss (n = 279), foreign DNA profile was obtained in 55% of the cases. Comparative analysis for each sample type is presented in Table 2.

3.2.5. Washed themself

We examined whether foreign DNA could still be retrieved from skin swabs when the complainant washed themself after the assault and prior to the collection of forensic samples. A total of 133

Table 2
Proportion of samples/cases for which a foreign DNA profile was obtained in cases with or without reported memory loss. Vaginal samples include vaginal swab and vaginal rinse.

	Memory loss 285 cases	No memory loss 279 cases
Vaginal samples	21%	32%
Mouth rinse	2%	4%
Anal swab	11%	12%
Skin swab	32%	41%
Cases	**40%**	**55%**

skin swabs were included in the SAEK evaluated, but information whether the complainant had washed or not was missing for 4 swabs, so results from 129 skin swabs were compiled. Results show that the proportion of skin swabs for which a foreign profile was obtained was similar whether or not the complainant mentioned bathing or showering when skin swabs were collected within 24 h after the assault (Table 3). When sampling was done between 24 and 48 h after the event, this proportion was lower when the complainant washed themself (5%) than when no washing occurred (47%). For all TSIs combined, a foreign profile was obtained for 19% of skin swabs when the complainant washed themself and 42% of skin swabs when the complainant did not.

Because foreign DNA can be present on the skin of individuals due to innocuous everyday interactions, DNA profiles found from skin swabs are not necessarily related to the sexual assault and could have been transferred to the skin after the assault. To have a better understanding of the persistence of DNA collected from skin swabs, a subset of foreign profiles were further classified as relevant DNA profiles when the probability that they came from the assailant was very high. DNA profiles from skin swabs were considered relevant only when they corresponded to a profile found on an internal sample or when they corresponded to the suspect's profile. Overall, the proportion of relevant profiles obtained from skin swabs when the complainant had washed themself was not negligible (8%), but lower than when no washing occurred (33%).

3.2.6. *Supplementary evidence*

We also evaluated the proportion of supplementary evidence (skin swabs, undergarments, clothing and bedding) for which a foreign DNA profile was obtained. A total of 133 skin swabs were processed: 35% yielded a foreign DNA profile and 26% a relevant DNA profile (see section above for the distinction between foreign and relevant). Skin swabs collected from the neck/ear or the breast area yielded the largest proportion of foreign DNA profiles (Table 4).

We also assessed the prevalence of foreign DNA profiles obtained from a complainant's clothing and bedding, when no profile had been obtained from the Stage 1 samples. The number of foreign/relevant DNA profiles detected on clothing and bedding is presented in Table 5. Although panties/briefs are the items of clothing most frequently analyzed (n = 122), bras, pants/shorts and shirts had larger proportions of samples yielding a foreign DNA profile.

Table 4
Proportion of skin swabs yielding foreign and relevant DNA profiles. Relevant profiles are reported as the proportion of the total number of samples.

Skin swabs	n	Foreign profile	Relevant profile
Neck/Ear	26	62%	46%
Breast	23	48%	22%
External vaginal area	23	13%	13%
Other areas	61	28%	23%
Total	**133**	**35%**	**26%**

4. Discussion

In the province of Québec, the forensic laboratory noticed a 25% increase in sexual assault cases between 2014 and 2017. Consequently, turnaround time lengthened and solutions were needed to increase efficiency. The first strategy put in place was to change the way sexual assault cases are processed by implementing a workflow with two Stages. In Stage I, only the internal samples (vaginal, anal, oral) are processed. Results from Stage I samples are then analyzed by a DNA analyst and discussed with the case investigator. Communication with law enforcement agencies after Stage I proved to be a good opportunity to ascertain whether the case was still active, knowing that around 12% of the sexual assault cases are closed by the agency or prosecution after exhibits are sent to the lab. This contributed to the marked reduction in total exhibits examined, along with the prioritization process. Stage II exhibits (skin swabs, clothing, bedding and objects) were processed only when deemed necessary, which corresponded to about half of the cases (52%) containing supplementary evidence. This prioritization procedure prevented the analysis of more than 600 exhibits for the 564 cases processed with the optimized workflow. Considering that the examination, screening and sampling of clothing and bedding is very time-consuming, reducing the analyses on these types of exhibits represents significant cost and time savings. With the implementation of the optimized workflow, the median turnaround time drastically decreased, going from 140 to 45 days. Because of this shorter turnaround time, deviation from regular

Table 5
Proportion of clothing and bedding belonging to the complainant that yielded foreign and relevant DNA profiles. Relevant profiles are reported as the proportion of the total number of samples.

Exhibits	n	Foreign profile	Relevant profile
Panties/briefs	122	18%	7%
Bras	42	45%	24%
Pants/shorts	46	41%	22%
Shirts	23	48%	22%
Bedding	31	32%	16%
Total	**264**	**31%**	**14%**

Table 3
Proportion of skin swabs yielding foreign and relevant DNA profiles when the complainant reported washing themself or not, separated by TSI.

	TSI	Skin samplesanalyzed	ForeignProfile	Relevantprofile
Bath or shower	<24 h	17	35%	12%
No bath nor shower		78	41%	35%
Bath or shower	24–48 h	19	5%	5%
No bath nor shower		15	47%	27%
Bath or shower	Overall (0–48 h)	36	19%	8%
No bath nor shower		93	42%	33%

procedures to ensure timely results for urgent cases due in court occurred less frequently.

When cases were processed with the optimized workflow, a foreign DNA profile was obtained in 44% of cases, a similar rate to what has been reported elsewhere [15–17]. However, this represents a slight decrease in investigative power compared to the extensive workflow (53%) and to results obtained by our own laboratory a decade ago (46–56%, for teenagers and adults respectively, [14]. This difference could be attributed to supplementary exhibits that were not processed and that could have yielded foreign DNA profiles. A longer average delay between the sexual assault and the forensic examination or an increasing number of unfounded allegations are other hypotheses that could be proposed to explain this slightly lower investigative power.

The second strategy put in place was to look at data from casework to guide resource allocation by identifying the likelihood of cases and samples to yield foreign biological material. As the probability of recovering a foreign profile on the complainant's body rapidly decreases with time, the time since intercourse (TSI) is an important factor to assess. In that context, we evaluated whether our current TSI guidelines, established in 2009, are still appropriate by looking at the proportion of samples for which a foreign DNA profile was obtained for all TSIs. Although we did not formally evaluate the success for samples with TSI longer than our guidelines, the very small proportion ($\leq$5%) of samples yielding foreign DNA profile in the TSI closest to the maximum recommended indicates that longer intervals would not lead to an important increase in the investigative power. Although our current TSI guidelines generally align with those previously reported [18–22], increased specificity of megaplex STR kits, Y-STR profiling and enhancing techniques may allow the detection of foreign biological material for up to 7 or 9 days [23,24]. Laboratories using these kits and techniques may thus need to reassess their recommended TSIs.

Redundancy of results within a case is rarely needed, especially when looking at results from the same body area. With that in mind, we assessed whether having two vaginal samples (vaginal swab and vaginal rinse) provided complementary or redundant information. Although in most cases the same result was obtained for both samples, a few instances were recorded where a foreign DNA profile was established from the vaginal swab and not the vaginal rinse, or vice versa. Because vaginal penetration is reported in a large proportion of sexual assaults [15,25–29], vaginal samples often represent the most critical piece of evidence in sexual assault cases. It may thus be appropriate to use two vaginal samples to maximize the probability of recovering foreign biological material. However, handling liquids has some drawbacks, such as the risks of spills and the need for refrigeration of SAEKs to avoid bacterial growth that could damage DNA [30]. Therefore, laboratories may be interested in finding an alternative to the vaginal rinse. Using a second swab sample collected deeper in the vaginal cavity is a possible solution [22,31].

We also looked at whether foreign DNA profiles can still be retrieved from skin swabs when the victim washed themself after the assault and prior to the collection of forensic evidence. When discussing results from skin swabs, it is important to take into account that DNA can be present because of regular everyday interactions, particularly for exposed regions such as arms, neck, ears, etc. To discuss persistence of DNA on skin swabs, we will therefore use a conservative approach and consider only relevant profiles, i.e. those corresponding to a profile obtained from an internal sample or from a suspect. Because a comparison to the suspect profile is performed only in a minority of cases, and because skin swabs are generally not analyzed when a foreign DNA profile is obtained from internal samples, this approach may underestimates the persistence of DNA on skin swab. Although the proportion of skin swabs yielding a relevant profile is lower when the complainant showered or bathed (8%) compared to when the complainant did not (33%), results show that DNA from the assailant can still be obtained from skin swabs when the victim washed themself after the assault. Although body fluid identification has not been performed in this study, saliva and semen are usually the source of foreign DNA that can be expected in sexual assault cases as a result of kissing, licking, biting, spitting or ejaculation. Previous studies have reported that interpretable DNA profiles can be obtained from saliva and semen stains after being immerged in water [32–38]. However, the permeability of skin is quite different from fabric, and hand washing is one of the main factors contributing to the loss of foreign DNA under fingernails [39]. When the complainant reports washing themself, that term emcompasses a variety of activities, ranging from intensive scrubbing with soap to a quick rinse under water that may not dislodge much of the foreign DNA. There is also the possibility that in the context of the medical forensic exam, the victim may not be comfortable saying that she has not washed. Skin swabs should be collected when appropriate according to the case circumstances, notwithstanding whether washing occurred or not, and those kits/samples should be submitted to forensic laboratories [40].

Condoms are not used in a majority of sexual assaults [41,42]. However, even when their use is reported, forensic samples should be collected as usual. Indeed, results from our study show that DNA from the assailant can be obtained even when a condom was used, whether vaginally or anally. The same recommendation could be made for cases in which the complainant reported memory loss, as a foreign DNA profile was obtained in a sizeable proportion of those cases (37%), a proportion similar to the one indicated by Ref. [17]. When victims are unable to provide details regarding the particular actions committed during the sexual assault, the procedure is usually to collect all of the internal samples (oral, anal, vaginal) and to collect the undergarments of the victim so that the crotch of the panties and the inside of bras can be sampled. Our data from supplementary evidence in casework indicate that a high proportion of skin swabs from the neck/ear and breast areas yield a foreign DNA profile (62% and 48%, respectively). Therefore, collection of these samples would be relevant as well for cases involving memory loss or partial recollection of the events. However, because the neck and ears are exposed, regular social interactions could lead to the deposition of foreign DNA on these areas. On the other hand, the breast area is usually more concealed and less prone to the collection of foreign DNA in social interactions.

When no results are obtained from internal samples, clothing and bedding can be valuable sources of DNA evidence. A considerable proportion of samples collected from bras yielded a foreign DNA profile (45%), corroborating the results obtained from the breast skin swabs. Although panties were the most common piece of clothing analyzed, the proportion of samples yielding a foreign DNA profile was much lower for these (18%) than for regular clothes (pants/shorts: 41% and shirts: 48%). Because foreign profiles in panties often comes from vaginal or anal discharge, if panties were sampled for all sexual assault cases, including those with a male profile in the vaginal samples, the proportion yielding a foreign DNA profile would probably be much higher. Also, whereas regular clothes are generally sampled only when a suspicious stain is observed, the crotch of panties and the cups of bras are routinely sampled regardless of the presence of stains.

Because DNA can persist on objects for extended periods of time [43–46] and sperm cells remain on fabrics even after being washed [32,35,37,38], the relevancy of foreign DNA found on these exhibits in relation to the sexual assault needs to be examined closely. As the forensic community is moving towards an evaluative reporting approach [47–50], where the question of how DNA got deposited

on an exhibit is as important as knowing whose DNA it is, it could be interesting to examine our data from supplementary evidence from an activity-based perspective, for example by looking at background DNA levels.

5. Conclusion

Data from this study were not obtained from controlled experiments but rather from casework. As such, they are subject to a higher level of uncertainty due to potentially inaccurate or incomplete recall and/or report of the sexual assault. On the other hand, data from casework have the advantage of being easier to generate and encompass a wider variability of case circumstances than could be obtained from mock samples.

The analysis of more than 500 cases showed that the forensic collection of evidence should proceed in the same way regardless of whether the complainant reported washing themself, the use of a condom or memory loss. Raising awareness among investigators, nurses and sexual assault examiners will ensure that all relevant samples are collected and sent to the forensic lab for analysis.

Declaration of competing interest

None.

Acknowledgments

The authors wish to thank Karine Fiola and Valérie Clermont-Beaudoin for proofreading.

References

[1] Rotenberg C, Cotter A. Police-reported sexual assaults in Canada before and after #MeToo, 2016 and 2017. Available: https://www150.statcan.gc.ca/n1/pub/85-002-x/2018001/article/54979-eng.pdf.
[2] P. Saint-Martin, M. Bouyssy, P. O'Byrne, Analysis of 756 cases of sexual assault in Tours (France): medico-legal findings and judicial outcomes, Med. Sci. Law 47 (2007) 315–324, https://doi.org/10.1258/rsmmsl.47.4.315.
[3] O. Ingemann-Hansen, O. Brink, S. Sabroe, V. Sørensen, A.V. Charles, Legal aspects of sexual violence–does forensic evidence make a difference? Forensic Sci. Int. 180 (2008) 98–104, https://doi.org/10.1016/j.forsciint.2008.07.009.
[4] R. Jewkes, N. Christofides, L. Vetten, R. Jina, R. Sigsworth, L. Loots, Medico-legal findings, legal case progression, and outcomes in South African rape cases: retrospective review, PLoS Med. 6 (2009), e1000164, https://doi.org/10.1371/journal.pmed.1000164.
[5] K.A. Muldoon, A. Drumm, T. Leach, M. Heimerl, K. Sampsel, Achieving just outcomes: forensic evidence collection in emergency department sexual assault cases, Emerg. Med. J. 35 (2018) 746–752, https://doi.org/10.1136/emermed-2018-207485.
[6] N.P. Lovrich, M.J. Gaffney, T.C. Pratt, C.L. Johnson, C.H. Asplen, L.H. Hurst, et al., National Forensic DNA Study Report, U.S. Department of Justice, 2004. Available, https://www.ncjrs.gov/pdffiles1/nij/grants/203970.pdf.
[7] T.C. Pratt, M.J. Gaffney, N.P. Lovrich, C.L. Johnson, This isn't CSI: estimating the national backlog of forensic DNA cases and the barriers associated with case processing, Crim. Justice Pol. Rev. 17 (2006) 32–47. Available, https://journals.sagepub.com/doi/abs/10.1177/0887403405278815.
[8] K.J. Strom, J. Ropero-Miller, S. Jones, N. Sikes, M. Pope, N. Horstmann, The 2007 Survey of Law Enforcement Forensic Evidence Processing, National Institute of Justice, 2009. Available, https://www.ncjrs.gov/pdffiles1/nij/grants/228415.pdf.
[9] J. Peterson, D. Johnson, D. Herz, L. Graziano, T. Oehler, Sexual Assault Kit Backlog Study, NATIONAL INSTITUTE OF JUSTICE, 2012. Available, https://www.ncjrs.gov/pdffiles1/nij/grants/238500.pdf.
[10] M.S. Nelson, Analysis of Untested Sexual Assault Kits in New Orleans, National Institute of Justice, 2013. Available, https://www.ncjrs.gov/pdffiles1/nij/242312.pdf.
[11] W. Wells, B. Campbell, C. Franklin, Unsubmitted Sexual Assault Kits in Houston, TX: Case Characteristics, Forensic Testing Results, and the Investigation of CODIS Hits, Final Report, National Institute of Justice, 2016. Available, https://www.ncjrs.gov/pdffiles1/nij/grants/249812.pdf.
[12] R. Lovell, M. Luminais, D.J. Flannery, L. Overman, D. Huang, T. Walker, et al., Offending patterns for serial sex offenders identified via the DNA testing of previously unsubmitted sexual assault kits, J. Crim. Justice 52 (2017) 68–78, https://doi.org/10.1016/j.jcrimjus.2017.08.002.
[13] C. Wang, L.M. Wein, Analyzing approaches to the backlog of untested sexual assault kits in the, U.S.A. J. Forensic Sci. 63 (2018) 1110–1121, https://doi.org/10.1111/1556-4029.13739.
[14] F. Gingras, C. Paquet, M. Bazinet, D. Granger, K. Marcoux-Legault, M. Fiorillo, et al., Biological and DNA evidence in 1000 sexual assault cases, Forensic Sci. Int.: Gene. Supplement. Ser. 2 (2009) 138–140, https://doi.org/10.1016/j.fsigss.2009.09.006.
[15] S. Jänisch, H. Meyer, T. Germerott, U.-V. Albrecht, Y. Schulz, A.S. Debertin, Analysis of clinical forensic examination reports on sexual assault, Int. J. Leg. Med. 124 (2010) 227–235, https://doi.org/10.1007/s00414-010-0430-z.
[16] A. Sudupe Moreno, Age differences among victims of sexual assault: a comparison between children, adolescents and adults, J. Forensic Leg Med. 20 (2013) 465–470, https://doi.org/10.1016/j.jflm.2013.02.008.
[17] J.E. Kerka, D.J. Heckman, J.H. Albert, J.E. Sprague, L.O. Maddox, Statistical modeling of the case information from the Ohio attorney general's sexual assault kit testing initiative, J. Forensic Sci. 63 (2018) 1122–1133, https://doi.org/10.1111/1556-4029.13697.
[18] R. Dziak, L. Parker, V. Collins, S. Johnston, Providing evidence based opinions on time since intercourse (TSI) based on body fluid testing results of internal samples, J. Can. Soc. Forensic. Sci. 44 (2011) 59–69, https://doi.org/10.1080/00085030.2011.10768142.
[19] B.B. Hellerud, M. Bouzga, P. Hoff-Olsen, B. Mevåg, Semen detection: a retrospective overview from 2010, Forensic Sci. Int.: Gene. Supplement. Ser. 3 (2011) e391–e392, https://doi.org/10.1016/j.fsigss.2011.09.057.
[20] C.E. Rogers, in: Amy N. Brodeur MFS (Ed.), The Prevalence of Intact Spermatozoa on Intimate Smear and Extract Slides: a Retrospective Case Review and Re-evaluation of Time since Intercourse Estimation, Boston University, 2012.
[21] D.G. Casey, K. Domijan, S. MacNeill, D. Rizet, D. O'Connell, J. Ryan, The persistence of sperm and the development of time since intercourse (TSI) guidelines in sexual assault cases at forensic science Ireland, dublin, Ireland, J. Forensic Sci. 62 (2017) 585–592, https://doi.org/10.1111/1556-4029.13325.
[22] US department of justice, National Best Practices for Sexual Assault Kits: a Multidisciplinary Approach, National Institute of Justice, 2017. Available, https://www.ncjrs.gov/pdffiles1/nij/250384.pdf.
[23] J. Kenna, M. Smyth, L. McKenna, C. Dockery, S.D. McDermott, The recovery and persistence of salivary DNA on human skin, J. Forensic Sci. 56 (2011) 170–175, https://doi.org/10.1111/j.1556-4029.2010.01520.x.
[24] E.K. Hanson, J. Ballantyne, Enhanced DNA profiling of the semen donor in late reported sexual assaults: use of Y-Chromosome-Targeted pre-amplification and next generation Y-STR amplification systems, Methods Mol. Biol. 1420 (2016) 185–200, https://doi.org/10.1007/978-1-4939-3597-0_15.
[25] C. Grossin, I. Sibille, G. Lorin de la Grandmaison, A. Banasr, F. Brion, M. Durigon, Analysis of 418 cases of sexual assault, Forensic Sci. Int. 131 (2003) 125–130. Available, http://www.ncbi.nlm.nih.gov/pubmed/12590050.
[26] C.M. Palmer, A.M. McNulty, C. D'Este, B. Donovan, Genital injuries in women reporting sexual assault, Sex. Health 1 (2004) 55–59. Available, https://www.ncbi.nlm.nih.gov/pubmed/16335297.
[27] P. Drocton, C. Sachs, L. Chu, M. Wheeler, Validation set correlates of anogenital injury after sexual assault, Acad. Emerg. Med. 15 (2008) 231–238, https://doi.org/10.1111/j.1553-2712.2008.00050.x.
[28] O. Ingemann-Hansen, S. Sabroe, O. Brink, M. Knudsen, A.V. Charles, Characteristics of victims and assaults of sexual violence–improving inquiries and prevention, J. Forensic Leg Med. 16 (2009) 182–188. Available, https://www.sciencedirect.com/science/article/pii/S1752928X08001790.
[29] R. Karanfil, A. Keten, C. Zeren, M.M. Arslan, A. Eren, Evaluation of sexual assaults in Turkey, J. Forensic Leg Med. 20 (2013) 404–407, https://doi.org/10.1016/j.jflm.2013.03.018.
[30] R. Alaeddini, S.J. Walsh, A. Abbas, Forensic implications of genetic analyses from degraded DNA—a review, Forensic Sci. Int. Genet. 4 (2010) 148–157, https://doi.org/10.1016/j.fsigen.2009.09.007.
[31] G. Fernie, Recommendations for the Collection of Forensic Specimens Complainants and Suspects, Faculty of Forensic & Legal Medicine, 2015. Available, http://ukafn.org/wp-content/uploads/2015/02/Recomendations-for-the-collection-of-forensic-specimens-Complainants-and-suspects-January-2015.pdf.
[32] H. Brayley-Morris, A. Sorrell, A.P. Revoir, G.E. Meakin, D.S. Court, R.M. Morgan, Persistence of DNA from laundered semen stains: implications for child sex trafficking cases, Forensic Sci. Int. Genet. 19 (2015) 165–171, https://doi.org/10.1016/j.fsigen.2015.07.016.
[33] S. Williams, E. Panacek, W. Green, S. Kanthaswamy, C. Hopkins, C. Calloway, Recovery of salivary DNA from the skin after showering, Forensic Sci. Med. Pathol. 11 (2015) 29–34, https://doi.org/10.1007/s12024-014-9635-7.
[34] H. Page, L. Harris, L. Taylor, T. Bishop, R. Newton, The recovery of semen from bath scrunchies, Aust. J. Forensic Sci. (2016) 1–9, https://doi.org/10.1080/00450618.2016.1153149, 0.
[35] T.G. Schlagetter, C.L. Glynn, The effect of fabric type and laundering conditions on the detection of semen stains, Int. J. Forensic Sci. (2017). Available, http://digitalcommons.newhaven.edu/cgi/viewcontent.cgi?article=1026&context=forensicscience-facpubs.
[36] J. Helmus, S. Zorell, T. Bajanowski, M. Poetsch, Persistence of DNA on clothes after exposure to water for different time periods-a study on bathtub, pond, and river, Int. J. Leg. Med. 132 (2018) 99–106, https://doi.org/10.1007/s00414-017-1695-2.
[37] A. Nolan, S.J. Speers, J. Murakami, B. Chapman, A pilot study: the effects of repeat washing and fabric type on the detection of seminal fluid and spermatozoa, Forensic Sci. Int. 289 (2018) 51–56, https://doi.org/10.1016/

j.forsciint.2018.05.021.
[38] S. Noël, K. Lagacé, S. Raymond, D. Granger, M. Loyer, S. Bourgoin, et al., Repeatedly washed semen stains: optimal screening and sampling strategies for DNA analysis, Forensic Sci. Int. Genet. 38 (2019) 9–14, https://doi.org/10.1016/j.fsigen.2018.10.002.
[39] N. Flanagan, C. McAlister, The transfer and persistence of DNA under the fingernails following digital penetration of the vagina, Forensic Sci. Int. Genet. 5 (2011) 479–483, https://doi.org/10.1016/j.fsigen.2010.10.008.
[40] D. Patterson, R. Campbell, The problem of untested sexual assault kits: why are some kits never submitted to a crime laboratory? J. Interpers Violence 27 (2012) 2259–2275, https://doi.org/10.1177/0886260511432155.
[41] Z.D. Peterson, E. Janssen, J.R. Heiman, The association between sexual aggression and HIV risk behavior in heterosexual men, J. Interpers Violence 25 (2010) 538–556, https://doi.org/10.1177/0886260509334414.
[42] K.C. Davis, P.A. Kiekel, T.J. Schraufnagel, J. Norris, W.H. George, K.F. Kajumulo, Men's alcohol intoxication and condom use during sexual assault perpetration, J. Interpers Violence 27 (2012) 2790–2806, https://doi.org/10.1177/0886260512438277.
[43] J.J. Raymond, R.A.H. van Oorschot, P.R. Gunn, S.J. Walsh, C. Roux, Trace evidence characteristics of DNA: a preliminary investigation of the persistence of DNA at crime scenes, Forensic Sci. Int. Genet. 4 (2009) 26–33, https://doi.org/10.1016/j.fsigen.2009.04.002.
[44] A. Linacre, V. Pekarek, Y.C. Swaran, S.S. Tobe, Generation of DNA profiles from fabrics without DNA extraction, Forensic Sci. Int. Genet. 4 (2010) 137–141, https://doi.org/10.1016/j.fsigen.2009.07.006.
[45] H. Nakanishi, M. Hara, S. Takahashi, A. Takada, K. Saito, Evaluation of forensic examination of extremely aged seminal stains, Leg. Med. 16 (2014) 303–307, https://doi.org/10.1016/j.legalmed.2014.04.002.
[46] R.A.H. van Oorschot, B. Szkuta, G.E. Meakin, B. Kokshoorn, M. Goray, DNA transfer in forensic science: a review, Forensic Sci. Int. Genet. 38 (2019) 140–166, https://doi.org/10.1016/j.fsigen.2018.10.014.
[47] A. Biedermann, C. Champod, G. Jackson, P. Gill, D. Taylor, J. Butler, et al., Evaluation of forensic DNA traces when propositions of interest relate to activities: analysis and discussion of recurrent concerns, Front. Genet. 7 (2016) 215, https://doi.org/10.3389/fgene.2016.00215.
[48] P. Gill, T. Hicks, J.M. Butler, E. Connolly, L. Gusmão, B. Kokshoorn, et al., DNA commission of the International society for forensic genetics: assessing the value of forensic biological evidence - guidelines highlighting the importance of propositions: Part I: evaluation of DNA profiling comparisons given (sub-) source propositions, Forensic Sci. Int. Genet. 36 (2018) 189–202, https://doi.org/10.1016/j.fsigen.2018.07.003.
[49] D. Taylor, A. Biedermann, T. Hicks, C. Champod, A template for constructing Bayesian networks in forensic biology cases when considering activity level propositions, Forensic Sci. Int. Genet. 33 (2018a) 136–146, https://doi.org/10.1016/j.fsigen.2017.12.006.
[50] D. Taylor, B. Kokshoorn, A. Biedermann, Evaluation of forensic genetics findings given activity level propositions: a review, Forensic Sci. Int. Genet. 36 (2018b) 34–49, https://doi.org/10.1016/j.fsigen.2018.06.001.